

Viewgraphs for Presentation

Nuclear and Alternative Energy Supply Options for an Environmentally Constrained World *A Long-Term Perspective*

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Can We Have One Without the Other?”

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ADDRESSING THE MAJOR ENERGY-RELATED CHALLENGES OF THE 21ST CENTURY

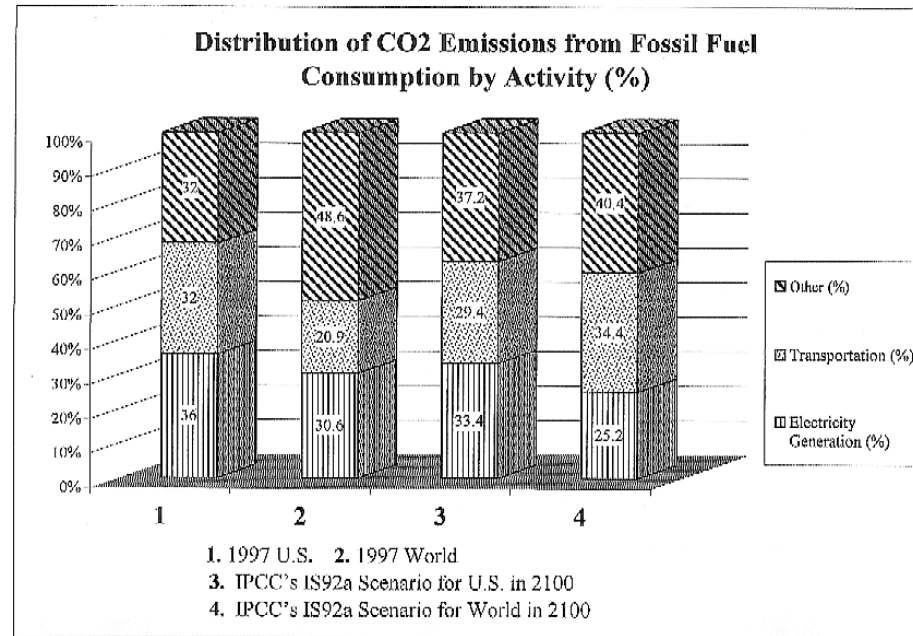
- **Additional energy supplies to support population growth (2X) and needs of developing countries**
- **Air pollution** (*reduce emission rate $\sim 10^2$ -fold over century*)
- **Alternatives to conventional oil/natural gas** (*production will probably peak in 2nd Qtr of century*)
- **Climate change** (*keep CO_2 level < 550 ppmv*)
- **Affordability of energy services**

➔ Radical technological change

➔ Decades of rapid growth for targeted new technologies

Understanding climate-change mitigation requires long-term (\sim century) perspective to appreciate scale of needed effort

CLIMATE CHANGE: MOST DAUNTING CHALLENGE



“BAU” Global CO₂ emissions:

6.2 GtC (1997, actual) → 20 GtC (2100, IPCC's IS92a)

Transportation + Other “Fuels Used Directly” = $\frac{3}{4}$ of “Problem”:

4.3 GtC (1997, actual) → 15 GtC (2100, IPCC's IS92a)

Fuels used directly/capita increase 1.4X (to $\frac{1}{4}$ US level 1998)

MAJOR OPTIONS FOR ACHIEVING NEAR-ZERO EMISSIONS IN POWER GENERATION

- **Nuclear fission**
- **“New” renewables** [*mainly wind, photovoltaic (PV)*]
- **Decarbonized fossil fuels + CO₂ sequestration**
(*esp. in deep geological formations—depleted oil and gas fields, beds of unminable coal, deep saline aquifers*)

NUCLEAR POWER

- **Nuclear power provided 16% of world electricity, 1998, but little if any net growth to 2020 expected at global level**
- **Nuclear power renaissance? Only if challenges of cost, safety, waste disposal, nuclear weapons link satisfactorily resolved**
- **Safety, waste disposal issues probably soluble technically; but waste disposal faces formidable political obstacles**
- **Weapons link would come into sharp focus if nuclear power → a significant contributor to climate change mitigation**

CLIMATE CHANGE MITIGATION/PROLIFERATION NEXUS

Nuclear power & climate change mitigation

- **2,700 GW_e nuclear in 2100 in IS92a with CO₂ emissions ~ 20 GtC/y**
- **If instead nuclear displaces all coal power → ~ 5,000 GW_e nuclear in 2100, & CO₂ emissions would be ~ 16 GtC/y**
- **If instead all nuclear power were replaced by coal power in 2100 emissions would be ~ 24 GtC/y**

Proliferation risks at high levels of nuclear power deployment

- **Proliferation risk especially difficult to manage with shift to Pu recycle, breeder reactors as response to U resource constraints**
- **Even with U from seawater + OT fuel cycles, keeping weapons link weak difficult with high levels of U enrichment activity required**
- **At high nuclear power deployment levels, clustering sensitive nuclear facilities in large, heavily guarded “nuclear parks” maintained under international control may be necessary**

WIND POWER

- **Grid-connected installed capacity grew 30%/y since 1996 to 17 GW_e in 2000 (0.24% of global electricity)**
- **Generation cost < 5 ¢/kWh; good prospects → 3 ¢/kWh by 2010-2015**
- **Huge potential: 20,000–50,000 TWh/y (1.5-4.0 X global electricity, 1997)**
- **Challenge: most good wind resources far from major markets**
- **But can bring remote wind supplies to market as baseload electricity with multi-GWe wind farms + CAES + HV transmission**
- **CAES (*compressed air energy storage*) can convert wind power to baseload electricity for 0.5 to 1 ¢/kWh additional cost**
- **Harnessing 20,000 TWh/y by 2100 (*equivalent to 2,900 GW_e nuclear*) → wind farms on 0.6% of land of inhabited continents, but WF infrastructure requires 5-10% of land; rest can be farmed, ranched, etc.**
- **In U.S. wind-rich farming/ranching regions WF royalties to farmers/ranchers likely to be ≥ current farming/ranching incomes**

PHOTOVOLTAIC POWER

- PV sales grew 15%/y, 1983-1999, reaching 200 MW_p/y, 1999
- Module costs have fallen, \$40/W_p (1976) to \$4/W_p (at present)
- PV competitive w/o subsidy in markets remote from electric grids but lags wind in central-station power applications (*costs* ~ 25-35 ¢/kWh)
- But large market opportunities soon for grid-connected distributed applications—esp. building-integrated systems near users
- PV system costs for residential rooftop PV falling: \$17/W_p (1984) → \$9/W_p (1992) → \$6/W_p (1996), and (*expected*) → < \$3/W_p after ~ 2005
- \$3/W_p can be achieved with “learned out” current technology + large-scale (100 MW_p/y) module production facilities
- At \$3/W_p PV cost-effective for ~ 10 million US homes @ 4 kW each with mortgage financing + net metering only (10 – 12 ¢/kWh)
- This early market will spur PV technological development → good prospects for central station costs ~ 4.5 - 5.5 ¢/kWh by 2030

COAL POWER WITH NEAR-ZERO EMISSIONS?

- Coal integrated gasifier/combined cycle (IGCC) plants are becoming cost-competitive with coal steam-electric plants (3.2 ¢/kWh), offering air pollutant emissions as low as for natural gas combined cycles
- IGCC technology also offers least costly route for coal to near-zero CO₂ emissions with commercial technology (*cost penalty* ~ 1.5 ¢/kWh); overall efficiency (~ 36%) not less than for typical new conventional coal steam-electric plants w/o CO₂ separation/disposal (~ 35.5%)
- Coal power cost w/CO₂ separation/disposal < for nuclear power, most regions; reduced costs likely w/advanced fossil energy technologies
- Growing scientific confidence that potential for secure CO₂ disposal in geological formations is perhaps several 10³ GtC—equivalent to large fraction of carbon in remaining recoverable fossil fuels
- Greatest sequestration potential: deep saline aquifers—but early deployment will focus on depleted oil/gas fields & beds of unminable coal (*to get benefits of enhanced oil/natural gas recovery & enhanced coal-bed methane recovery in conjunction with CO₂ sequestration*)

ZERO EMISSIONS FOR FUELS USED DIRECTLY?

- **Fuels used directly account for 2/3 of CO₂ emissions now & perhaps ¾ of emissions by 2100 (~ 15 Gt/y under IS92a)**
- **Climate stabilization cannot be realized without achieving deep reductions in CO₂ emissions for fuels used directly**
- **Least costly option: make H₂ from fossil fuels with CO₂ sequestration**
- **W/commercial technology: H₂ can be produced from NG (with CO₂ separation/disposal) for \$1/gallon, gasoline equivalent energy (*plant gate cost*)**
- **With advanced technologies H₂ from coal is likely to cost less**
- **Poor prospects that H₂ could ever be produced at costs competitive even with current H₂ from NG technology—via electrolytic processes (*based on nuclear, wind, or PV power*) or via thermochemical processes (*based on nuclear or solar heat*)**

NEEDS IN ADDRESSING 21ST CENTURY CHALLENGES

- **There are plausible combinations of energy supply technologies with which all major challenges can be addressed effectively:**

[E.g., emphasize: wind/PV for power generation; decarbonized fossil energy/CO₂ sequestration for fuels used directly]

- **Addressing challenges effectively with any set of options will require extraordinarily rapid deployment rates sustained over several decades that are not feasible under free market conditions**
- **Need public policies that: set goals for tackling challenges; support R&D; create market-launching incentives for promising radical innovations; foster competitive market conditions after market launch**
- **Establishing such policies and keeping them in place long enough to make a difference requires high degree of public support**
- **Needed policies can endure over decades in democratic societies only if targeted technologies are enthusiastically embraced by general public**

PROSPECTS FOR “SUSTAINED ENTHUSIASTIC EMBRACE” BY GENERAL PUBLIC

New renewables

Opinion polls/studies indicate PV, wind have best prospects for garnering broad public support

Fossil energy decarbonization/CO₂ sequestration

How will general public regard this advanced fossil energy option? Too soon to tell—technology unfamiliar to most

- **CO₂ not radioactive & not harmful if leakage rates can be kept low (*for which prospects seem to be good*)**
- **Most promising technologies also offer near-zero air pollution**
- **Best prospects if renewable energy enthusiasts come to see these as complements to renewables, rather than competitors**

PROSPECTS FOR “SUSTAINED ENTHUSIASTIC EMBRACE” BY GENERAL PUBLIC (*continued*)

Nuclear power: Can public enthusiasm be rekindled/sustained?

- **Industry must first overcome intense hostility among many groups**
- ***Sustainable* nuclear renaissance likely only if new technologies come into market that are judged to be decisively better than alternatives**
- **If there were a nuclear renaissance, nuclear weapons connection would move to front & center stage at high levels of capacity deployment**
- **International “nuclear park” option might make most of general public comfortable with nuclear weapons link issue, but would national governments accept giving up some degree of energy sovereignty?**
- **Finally, there is risk that public policies/resources committed to resurrecting the nuclear option would weaken efforts to develop/commercialize non-nuclear technologies that could have far greater impact in climate-change mitigation**